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Materials and Processes

for Spacecraft and High Reliability Applications

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PRAXIS

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Talking of education, 'People have now a-days, (said he,) got a strange opinion that everything should be taught by lectures. Now, I cannot see that lectures can do so much good as reading the books from which the lectures are taken. I know nothing that can be best taught by lectures, except where experiments are to be shewn. You may teach chemistry by lectures—You might teach making of shoes by lectures!'

Samuel Johnson, 1766
(from Boswell's *Life*)

This book is dedicated to Cato and Dennis

Preface

This book, as implied by the title page, is an extensively revised version of the former "*Metallurgical Assessment of Spacecraft Parts, Materials and Processes*" published in 1997. The present title has been modified to set it apart from the previous work and describe its expanded content. The book has become more voluminous, this reflects the huge advances made during the past 20 years when we have witnessed the increased usage of modern materials and manufacturing techniques that were unforeseeable when the former book was written. Also, the number of case studies and amount of general information has been extended to become a source for engineers, space scientists, laboratory experimenters and technicians. Although much of the book considers metallurgical aspects of spacecraft engineering, there is now basic advice covering organic and ceramic materials as well as techniques available for assembling them into essential sub-systems, reliable parts and structures.

A good number of the original illustrations are retained but many new ones have been added. Several images reflect the quite remarkable outcomes of space projects. These include high resolution images of Earth taken by satellites which are relevant for surveillance and the forecasting of weather. Also included are fly-by images of enigmatic little moons and comets captured by spacecraft after many years of voyaging in search of life and the origins of water in our own Solar System. Equipment on-board the International Space Station and satellite-based communications are mentioned. These have all been made possible by breakthroughs in materials, processes and electronic-engineering.

Plato saw engineers as "doers" not "thinkers". From ancient times no one expected engineers to question what they were asked to build and consider the consequences of such achievements. Nowadays engineers are more confident in their social role and have learned to say "no" when the products are questionable or environmental damage may occur—the generation of space debris is one pertinent example. Hopefully, some "lessons learnt" guidance may ensue from the case studies and failure analyses recorded in this book. In 1986 engineers said "go" to the Challenger launch—other engineers said "no" but were over-ruled and the space shuttle exploded shortly after lift-off. It is only in hindsight that we understand that decision making can be extremely difficult, but such decisions must consider input from all engineering disciplines and the recognition of material properties is vital.

A casual review of the Contents and Index will suggest to the reader that the subject matter is likely to be of interest not only to spacecraft engineers, but in the broader sense, to workers in quite different areas where metals, organic materials, composites, ceramics and glass are used under terrestrial conditions or within high vacuum systems. Advancements in technology always produce questions related to the reliability of new systems. Materials testing to agreed codes of practice have been shown to help maximise the reliability of new materials, processes, and applications. Metallography (or "materialography") has led to an increased understanding of failure modes. Much emphasis of this book has been placed on failure analysis investigations. Each case must be developed in a logical manner—large-scale

(macroscopic) features are initially investigated, then the microscopic features of the materials involved. Test specimen or samples of spacecraft hardware must be meticulously prepared, then examined using both light and electron microscopy. It is amazing how these techniques have evolved and how the recording of images has progressed. The author and his metallurgist contemporaries may well remember early student days when contributions to reports were exquisitely detailed hand drawn micrographs or images captured on photographic plates. The digital revolution has now enabled all levels of detail to be recorded using super-resolution microscopes and the future seems to be heading towards 3-dimensional microscopy.

In this book I have endeavoured to achieve a reasonable balance between general background knowledge and in-depth technical information. An elementary understanding of metals and materials on the part of the reader is assumed. I have deliberately excluded a comprehensive account of the techniques employed in modern materials laboratories (unless specifically related to unusual space material test methods). Many texts are available and cited in the Reference section. The Appendices have been extended and include many Tables related to: spacecraft materials' properties; alloy comparisons as they may be procured in different countries; a simplified M&P management guideline for universities; and, examples of Declared Materials and Processes Lists.

The space industry is a key sector in driving economic growth and creating new jobs. By 2030, the global space economy is predicted to be worth £400 billion per annum. At the time of writing, the European space manufacturing industry alone has an unprecedented overall turnover at £6 billion and a total direct employment of 38,000 persons. New spaceports will be established and spaceplanes are most likely to be the next generations' means for transporting commercial and scientific payloads into orbit. Many future spacecraft engineers, space scientist and technologists, all specialists in their own fields, may be aghast that some fundamental, 'old-hat' information is contained in this book. But it is the lessons-learnt scenarios that have brought us to where we are today. The industry is expanding and new employees need to learn from our past mistakes and, at least, understand why certain design rules exist.

The wide acceptance of the previous book has been most welcome, and I hope the new changes and additions will also find approval by my colleagues in the space industry and others in the wider engineering community.

Bosham, West Sussex
December 2015

Barrie D. Dunn

Acknowledgments

This book has been brought about by the blending of various published research and investigation projects that I have undertaken as a metallurgist for the European Space Agency, from some written works of others and from personal friends. I am especially grateful to the late Dr. Jacques Dauphin my former Division Head at ESA who gave the encouragement to undertake the writing of the earlier book. He was a native of the French province of Lorraine, where the motto is 'Qui s'y frotte s'y pique' which loosely translates to 'gather thistles, expect prickles'—quite an apt maxim for those of us who have been involved with failure investigations. I also acknowledge the help received from my former ESA colleagues: Dr. Ton de Rooij, Jack Bosma, Guy Ramusat, Adrian Graham, David Collins and David Adams. Special thanks are also given to Dr. Ernst Semerad, Dr. A. Merstallinger, Grazyna Mozdzen and Markus Fink of the Aerospace and Advanced Composites GmbH (formally ARC), Wr. Neustadt, Austria, with whom I have had many years of professional collaboration. As previously stated, there has been a marked progress in this field of materials technology, resulting in significantly more citations to references in this Edition, but even so, the bibliographic information certainly is not complete. Where I have forgotten to cite a reference or credit an image I hope the author will forgive my oversight.

I am also grateful to ESA and NASA for some of the illustrations used in the book. It should be noted that the opinions expressed in this book are those of the author and do not necessarily reflect the policy of the European Space Agency.

Let me add a special note of thanks to my late wife, Hanneke, my son, Martin, and my daughter Harriet, for their patience through the spare-time hours that went into the making of the previous Edition. Also, to Anne for her unswerving support and help editing this present book. Stephen Hulcroft's assistance at BlueFish Computer Services, Chichester is appreciated. I also wish to thank Clive Horwood, and the staff at Springer Praxis Books in Germany (Ms. Janet Sterritt) and India (Mr. Antony Raj Joseph and Ms. Sivajothi Ganesarathinam), for their assistance during the publication of this book.

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